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DECISION-MAKING PROCESS OF AN
ANTISUBMARINE WARFARE COMMANDER

by

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Decision-Making Process of an
Antisubmarine Warfare Commander

by

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ABSTRACT

This thesis represents a study of the decision-making process of an Antisubmarine Warfare Commander (ASWC). Several real world operational issues are analyzed and discussed as to how they can influence his thought process when making decisions. One approach to model this individual's thought process was accomplished by ALPHATECH, INC. By utilizing an ASW scenario, it evaluates how an ASWC makes his tactical decisions to track submarines based upon pieces of received acoustical information. In order to improve this model's representation of a realistic operational environment, a conceptual ASWC decision-making model is provided here.

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I. INTRODUCTION

For the past two decades, the Soviet Union has oriented its naval policy toward the production of a large scale and formidable submarine force.* Particularly, in the last ten years there has been a mass production of various Soviet Nuclear Attack submarines which can launch cruise missiles and/or torpedoes from over-the-horizon against surface vessels. In view of this, the United States has placed great emphasis in the direction of Antisubmarine Warfare (ASW). Specifically. acoustical hydrophone sensors (sonobuoys and towed-arrays) have been developed to detect submarine frequency signatures that are associated with specific submarine hulls. It is with this information, that an ASW tactician can localize and track a potential threat submarine and attack if necessary.

It takes years of experience to become an expert in ASW. One such person is an Antisubmarine Warfare Commander (ASWC). He possesses an in-depth knowledge of the enemy's threat capabilities and the associated tactics needed to counter this threat in a hostile environment. He also is aware of the limitations of his own assets (surface and airborne) with respect to what they can or can not do. Armed with this basic foundation of knowledge, an ASWC developes his approach to solving an ASW problem. Therefore, his ability to make precise decisions based upon his years of experience is a very important element in any ASW problem; as his decision can influence the outcome of an ASW scenario and ultimately the survivability of a carrier battle group.

To describe such an individual is extremely difficult because the human decision-making process is a very complex system. Each individual perceives problems differently and their course of action to solve a given problem may be totally different as compared to someone else. Decision-making can also be difficult due to the lack of accurate information which can easily lead to uncertainty. This becomes an important issue especially when a decision-maker must choose from a list of alternatives that are vague in nature. This is a common occurance for an ASWC. The received acoustical information may be inaccurate due to unresolved bearing ambiguity or merely irregularities that are inherent with sound propagation traveling in the ocean. Therefore, modeling an ASWC decision-maker is an arduous task that must encompass a variety of human characteristic traits.

One attempt to model an ASWC decision-maker has been accomplished by ALPHATECH, INC. Utilizing the discrete Kalman filter, they have mathematically modeled an ASW tracking scenario. Although, lacking in complexity, it does serve as a basic model. To evaluate the models performance, US Naval Officers were utilized as subjects to çompare their results with those attained by the model. The assumption being, that if the model's performance and the performance of the experimental subjects were correlated, then it can be considered a valid representation of the ASWC's decision-making process. Additionally, one other major issue, was to determine if a simulation model possesses validity. This was judged by whether the model represents a true representation of what is desired to be simulated. Specifically, for an ASWC, the model must represent a real world operational environment.

Acknowledging this, the choice of this study was to discuss the ALPHATECH, INC., ASWC simulation model. In doing so, their assessment scenario was analyzed by looking into the parameters utilized to justify the models existence. Further, the scenario is evaluated in order to determine if it is a true representation of an operational environment. The model itself, is a good assessment; however, current operational battle groups have better and more capable means of attaining acoustical information then presented by their model. Therefore, using the experimental parameters established by ALPHATECH, INC., an alternative scenario is provided with a following discussion presenting some of the new sensor gathering equipment available in the fleets today.

Lastly, the ASWC himself was analyzed. To accomplish this, the chosen approach was to model a conceptual ASWC taking into consideration a real world operational environment. This is done by examining several topics that influence his thought process when making decisions. The complexity of this issue presents various implications ranging from, for example, personnel problems to equipment malfunctions. Each of which, whether alone or occuring simultaneously, do reflect upon his decision-making process. Therefore, we identify why this sort of individual is such a unique person and yet, he is the critical element and focal point in an ASW confrontation.

II. THE ASW PROBLEM

The decisions required in an Antisubmarine Warfare (ASW) scenario are crucial for the survival of naval vessels and the international rights to free passage of the open oceans. In view of this major concern, research efforts attempting to build a simulation model for an Antisubmarine Warfare Commander (ASWC) are of interest to the Navy. The model should identify the decision process that an ASWC would encounter in an ASW scenario. This is not an easy task, for there are endless variables that may or may not be confronted in the overall decision analysis. In many situations, the sequence of events rely solely on a previous decision. If a poor judgement decision is rendered, the follow-on events can easily lead the scenario astray and yield erroneous ASW results. However, prudent modeling will allow the decision maker to correct for a bad decision (or guess) as the scenario developes.

ALPHATECH, INC., has devised a fundamental ASWC simulation. This model currently addresses several tactical decisions confronted by an ASWC and outlines his formulated thought process in various scenarios. Specifically, this cognitive model is attempting to provide the following:

1. To identify the cognitive limitations or biases of the ASWC that most significantly impacts the total, or overall, ASW system performance. These results could be used to guide the development of the new training procedures or decision support systems.
2. To evaluate more reliably the effectiveness of future decision support systems, operational modifications, or tactical doctrine on total ASW system performance by replacing primitive representations of high-level commanders available in extant large-scale simulations.
3. To predict the impact of individual cognitive differences on the ASW system. (Ref. 3:p. 1)

The model does not provide an ideal simulation, but does establish an initial foundation upon which to build. For an ASWC model should serve as a tool to aid and educate the trainee. In a rapidly growing technological society, there is always need for improvement to a model to coincide with current technology or existing equipment. To improve upon the ALPHATECH model and based on operational experience, a realistic ASW scenario utilizing a US aircraft carrier battle group and a generic Soviet submarine is provided in order to bring validity into the ASWC's decision process. This scenario is based on knowledge of the Soviet submarine threat and factors associated with the flow rate of information to the ASWC.

A. SOVIET SUBMARINE THREAT

The optimum scenario would indeed allow the ASWC to be alerted of the exact location of an enemy submarine before it enters into the cruise missile range envelope of our own naval forces. However, this is not a realistic assumption for past and especially present ASW operations. History dictates that the subsurface threat has and will in the future, present disruption in sea lines of communication. Recently, the Chief of Naval Operations wrote the following with regard to anti-submarine warfare:

> It will be essential to conduct forward operations with attack submarines, as well as to establish barriers at key world chokepoints using maritime patrol aircraft, mines, attack submarines, or sonobuoys, to prevent leakage of enemy forces to the open ocean where the Western Alliance's resupply lines can be threatened. Maritime air and anti-submarine warfare units will be involved, along with offensive and defensive mining. As the battle groups move forward, we will wage an aggressive campaign against all Soviet submarines, including ballistic missile submarines. This aggressive action ensures that we prevent such losses as the Germans inflicted on allied shipping between January and July of 1942 when 14 of 50 then-operational German U-boats sunk 450 ships. (Ref. 1:p. 11)

The current generation of Soviet submarines has improved significantly with respect to detection by acoustical sensors. These technological advancements have brought the Soviets much closer with regard to difficulty of detection to that of the United States submarines. This aspect alone, has caused the United States to expend a tremendous amount of effort in attempts to combat this underwater threat. Specifically, the Soviets have significantly decreased their submarine radiated energy noise levels. This recent noise reduction has caused a major concern in the US Navy's ASW attitude and posture. The Soviet threat exists and is real. The many years of enjoying the tactical advantage of detecting noisy submarines is slowly dwindling.

Soviet made cruise missiles are extremely accurate and very lethal. Anti-surface cruise missiles can be launched at targets from 30 to 300 nautical miles (nm). The long-range cruise missiles generally must be fired from the surface and require midcourse guidance from another ship, submarine, or aircraft. The short-range cruise missiles (less than 100 nm) are fired while the submarine is submerged. These missiles require no external guidance; the targets are located by the submarines own sonar (Ref. 2:p. 23). Possessing this capability, the combination of long range cruise missiles coupled with submarine radiated noise reduction has certainly impacted the ASWC's role in Naval Warfare.

B. INFORMATION FLOW

Without question, uncertain data and time late rate of received data flow increase the anxieties and stress levels of the ASWC. In addition, acoustical information is not and will not be in the foreseeable future, a refined science. For bearing ambiguity, operator expertise or merely the human overload associated with the man/machine interface, increases the level of the human "guess factor". Operator fatigue, verbal telephone miscommunications (sound powered phones) or inexperienced personnel are examples which add to the uncertainties which add to the ASWC's dilemma. Efforts to specifically focus on education and/or training requirements is a problem area that the Navy continuously strives to improve. However, uncertainty can only be suppressed through continued rigorous fleet naval exercises and improving academic classroom requirements.

Flow of information can easily be disrupted by machinery. Equipment malfunction or improperly tuned avionics can severely degrade a ships ASW capability or provide information which is not within normal operating parameters. Reliability of hardware in a salt environment and the shipboard atmosphere together, complicate the essential need to maintain equipment at its highest efficiency. For a salt environment increases corrosion rate and shipboard vibrations and motion increase component failure rate. However, age and wear-and-tear produces many questionable reliability factors. We are in an era where standard everyday equipment is extremely sophisticated. This degree of complexity, requires maintenance personnel to possess a very strong technical background. This many times is not the case. For mechanical failures can not be perceived and technical manuals do not address many solutions to fix certain equipment. Additionally, spare parts are essential to perform routine maintenance. It is all too frustrating to have necessary equipment not be in a functional status for lack of parts. Occasionally, the absence of critical parts severely degrades a units ability to respond in a time of crisis. Specifically, acoustical parts to repair surface ship sonars and towed arrays, aviation parts to repair the onboard helicopter so as to maintain flyable status and parts to repair internal equipment that process raw acoustical data for operator display analysis. This is not an overnight problem, but in some cases can last days, weeks or even months. It is only through experience and knowledge of these variables, that the ASWC must understand the abilities of his assets and place them where he will attain the highest tactical advantage.

The question now becomes how does an ASWC cope with finding enemy submarines if information flow is questionable and/or inaccurate? Knowing the fundamentals of decision theory, as information flow increases, what sort of decision process is encountered in order to ensure that the best solution is attained? These questions certainly will not provide exact answers because there are endless scenarios where different thought paths are needed. Therefore, to model such behavior is extremely difficult, if in fact possible.

It must be assumed that the ASWC has surrounded himself with a high quality and experienced staff. Each individual is an expert in his field and understands his fellow shipmates professional expertise. Once achieved, most staff collected advice can now be assumed to be fact or the best alternative to a decision. This is a rather bold assumption, for many more times than desired, personnel filling a staff position, were selected merely because his new duty assignment coincided with a timely fit to fill such a billet. However, billet assignment by maximizing resource management to get the best people in the proper jobs is a separate issue unto itself.

C. SCENARIO

Succinctly, the ASWC's responsibility is to detect and to deter enemy submarines using a variety of surface, subsurface, and airborne platforms (Ref. 3:p. 3). The responsibility commences with the first piece of sensor or visual information. Assuming a hostile environment, a current realistic fair assessment, would be to expect first information to be achieved via acoustical sensor(s). The ASWC should be privy to known subsurface threats operating in his local area. Therefore, how valid is this first piece of information? The ASWC must consider and evaluate the following:

1. For the sensor that made initial contact, how much of a weighting factor can be associated with the validity of its unknown contact? Specifically, the history behind that sensor's false alarm probability.
2. Should the contact be considered valid if there are other sensors in the local area which did or did not gain contact that correlates?
3. Was contact attained actively or passively?
4. Does the current acoustical water conditions support the detection of a potential contact?

All of these questions need to be answered. In fact, a single piece of information only provides an alertment to a potential contact. This alertment serves as the stimulus to drive the ASWC into a potential ASW scenario.

Generally, the unit possessing the sensor will try to reestablish a second piece of contact information while maneuvering in its designated sector. It is extremely important that the unit remains in its sector inorder to maintain the crucial ASW integrity of the battle group. Once re-detection occurs and several acoustical sensor inputs are received, the contact will be identified as a POS SUB (possible submarine). The ASWC is now confronted with several options depending on the contact's bearing with relation to the battle group's course and speed. The battle group commander will undoubtedly vector the aircraft carrier and associated AAW (anti-aircraft warfare) escorts away from the subsurface threat. This tactical maneuver will also account for ensuring that the high value unit (aircraft carrier) is outside the envelope of the limiting-lines-of-approach (LLOA) of the submarine. The LLOA are the vector lines from the high value unit, for which a submarine must be within these prescribed vector parameters, inorder to fire a torpedo warhead.

> Torpedoes have a range of up to 30 nm. There are two types of torpedoes: wire-guided torpedoes and acoustic sensing torpedoes. Wire-guided torpedoes feed back acoustic information to the fire control operator for more precise mid-course targeting. Acoustic sensing torpedoes are dispatched along the bearing determined by the submarine's sonar, and use their own acoustic sensors to accurately seek the target. (Ref. 2:p. 23)

It can be seen that the ASWC's thought process is beginning to formulate many theoretical hypotheses. He is plagued with several critical decisions that require immediate action. Battle group survivability can be solely dependent upon what tactical measures are taken. Particularly, what ASW surface units should be dedicated to investigate the POS SUB contact? By removing one or more surface assets, how has this degraded the ASW protection from the main battle force? Should ASW helicopters be launched? Will the aircraft carrier be able to provide additional ASW airborne assets or is it unable to launch aircraft due to inadequate wind launch conditions? The ASWC is swamped with decisions to be made while simultaneously being flooded with past and current contact information. As more sensors acquire contact and localization of the submarine is underway, the ASWC becomes saturated with raw data. This saturation can and will reach levels approaching a severe overload condition. Excessive overload is avoided with most ASWC's because all less pertinent information is immediately filtered out or passed over and consumed by his operational staff. This allows the ASWC to focus on relevant decisions while absorbing staff recommendations for his prompt actions. However, it could increase his stress level if he does not have confidence in the input from his staff.

When the submarine contact is localized, classification can be an easy process depending on what sensors are in contact. Specifically, passive sensors reveal a frequency spectrum different from the local ambient environment. This stand out frequency usually is related to that of a submarine's signature. An average to experienced 'sensor operator can readily identify this acoustical signature. Through gram analysis and experience, he should be able to quickly scan the associated harmonics of the fundamental frequency and provide an accurate subsurface classification to the ASWC.

The submarines area of probability (AOP) particularly, localization, can consume time. As the AOP is sanitized with surface platforms or aircraft sonobuoys, refined localization parameters can take hours. If localization parameters are favorable, the ASWC must plan a strategy that will yield a high probability of kill. This attack mode presents several decision making avenues that the ASWC must consider. He must orient his weapon delivery unit into an envelope compatible to the weapon and that of the submarine. Once achieved and weapon delivered, the ASWC is confronted with other factors. In most cases, he can not immediately launch a second weapon due to mutual homing interference which is currently inherent in existing torpedoes. Therefore, he can only hope that the torpedo has acquired the submarine and is seeking to destroy, or he must wait until the torpedo has exhausted its fuel before he attempts a reattack. This time delay is critical and unfortunately can allow sufficient evasive submarine maneuvers for escape. If escape occurs and contact is not regained, it does not mean that the attack was unsuccessful because the ASWC has performed his duties in not allowing the submarine to attack the battle group. It may indeed prove only to be a postponement, but the current in extremis danger for the battle group, is over.

There are numerous variables that can present obstructions in the ongoing saga of ASW operations. The element of surprise is normally on the side of the subsurface threat. This advantage can provide an opportunity for a submarine to initiate an attack prior to detection by the surface battle group. Although the probability exists, it must be assumed that proper ASW battle group sector screening integrity will alleviate this potential occurance. The latest generation of Soviet submarine radiated acoustic energy noise levels have been significantly reduced and therefore harder to detect. Their current ability to operate in the low frequency domain does not allow for early detection as compared to noisy previous generation Soviet submarines. This

acknowledges the fact that acoustic signatures are difficult to see visually and hard to analyze in a timely fashion. Additionally, classical submarine tactics are to remain covert at all times. He has the advantage to maneuver into the limiting-lines-of-approach of an oncoming battle group and await for his optimum weapon release envelope. Once released, he has the ability to rapidly change depths and achieve an evasive sprint speed to exit safely the area of conflict. Thus, for this aspect alone, it is paramount that the ASWC acquire as early as possible, the presence of an enemy submarine.

Flexibility is a key element involved in an ASW prosecution. The measure of effectiveness of an ASWC is to be able to reevaluate past decisions and make a timely adjustment to the current scenario as new information becomes available. Again, ASW is not an exact science. Ambiguity and error probabilities are built into all sensors and processing equipment. As prosecution continues, error refinement becomes less and may change drastically the initial hypotheses. Recognizing this potential, it is imperative that the ASWC possess the keen quality to reorient his thought process and direct the new decisions where applicable.

True operational environments are extremely complex and not easy to function in when conducting anti-submarine warfare. We have patterned the ASWC's decision process and outlined many crucial areas where quick reaction is essential for battle group survivability. To put this into perspective, it can be viewed as inference versus choice.

> Inference is concerned mainly with assessment of evidence related to the relative likelihoods of various hypotheses being true, and the judgements being made are usually in the form of probabilities. Although these probabilities usually enter into the choice process, the distinctive feature of choice is the assessment of preferences regarding the various options available, or the predicted consequences or outcomes of these options. (Ref. 4:p. 25)

It is this reasoning that places an exorbitant demand on the ASWC to be precise and react accordingly.

It can be seen that one decision alone can influence but will not solve an ASW scenario. However, in the decision making thought process, inputs from an experienced staff coupled with reliable sensor information, should enable an ASWC to make the best tactical decision(s) given any ASW problem. A particular scenario can not be considered ideal because there can be as many mitigating variables as there are scenarios. Therefore, in order to justify and validate a model, the human decision

making process must be examined. Once understood, realism can be achieved by injecting into an ASWC model, state-of-the-art equipment currently available to the decision maker (ASWC). Possessing these qualities, most submarine threat simulations can be modeled. For any given scenario will accomplish the desired training results. Whether it is one ship against one submarine or ten ships against one submarine, the end result acts as a teaching aid to improve human reaction and efficiency, but at different complexities respectfully. In support of this, the next chapters discuss decision-making and examine how ALPHATECH, INC., approached their ASWC decision-making model.

III. DECISION-MAKING

Decision-making is the art of choosing from a list of alternatives a choice that will fulfill a given objective.

> First, goals or objectives must be known or identified (if these are not present, there is no motivation to decide or act). Secondly, current circumstances, insofar as they are relevant to the achievement of a goal, are assessed. If a discrepancy is perceived between goals and reality, options for action are generated. If more than one option is available, a choice will be made. (Ref. 4:p. 7)

It is difficult to assess how and why people make decisions, for there are many times that events occur in which everything is known and yet the decision itself, is hard to make. This is a common occurence. However, some decisions are so complex in nature, that a final course of action is extremely difficult or may in fact never be achieved. The decision-maker must rely on his experience and understanding of potential outcomes and uncertainties. Molded together, the decision-maker will make a choice that is the proper solution to a situation according to his interpretation or viewpoint.

Humans are constantly confronted with making decisions on a very frequent basis. They can be simple in nature where most of the alternatives to choose from are trivial. That is to say, the choice of action between two or more alternatives does not present serious consequences, such as deciding what color shirt to wear with a pair of pants. The ultimate choice is a human trait that is dependent on the decision-makers personality. On the other hand, many decisions are very complex and may affect people other than the decision maker. These decisions are usually made from experience and are often found in most critical professions where the decision-maker makes a choice inorder to ensure that the best possible solution is attained. "Decision-making is therefore something which concerns all of us, both as makers of the choice and as sufferers from the consequences, and there can be no doubt about the importance of the subject." (Ref. 5:p. 1) This is particularly noteworthy, for an ASWC makes decisions which can solely affect the outcome of the battle group survivability, both in human life and equipment. This is extremely significant, for a bad choice of action can easily result in the loss of naval vessels. Or perhaps, the ASWC may be confronted with a decision that will lead to the sacrifice of several ASW

units. This could be viewed in some sort of scenario exchange ratio, in which may cause the cost of lives and/or equipment, but will eventually provide for an optimum ASW solution. These types of decisions are not easy to make and require a decision-maker who is trusted and highly regarded for his abilities to make sound judgements.' He may require immediate action without time to fully analyze the alternatives despite the potential for enormous consequences. It is interesting to note, that the final decision may in fact be driven by a "gut feeling" or the probabilities of chance.

A. EXPERIENCE

A person from childhood through adulthood develops a behavioral pattern based on their past experiences. These past experiences may be pleasant such as a happy family reunion at Christmas or very traumatic such as putting a hand on a hot stove. Whatever the case may be, each experience is registered and stored in the library of the human brain. Although human experiences or events are all stored, they may not necessarily all be remembered. Such forgotten events can be associated with a particular number that gives the exact circumference of the planet Earth in feet or the spelling of a Soviet Navy shipping seaport (e.g., Petropavlovsk). It takes several rehearsals or memorizing in order to recall from memory. This feature of the human cognitive system will be addressed in the next section commonly known as short and long term memory.

Children in general, have a very brief past or library to recall from experienced events. However, as the child approaches and enters into adulthood, he establishes a foundation through past experiences that allow for rational decisions to be made. Each experience becomes more and more influenced by effects of their previous experiences. These experiences may not necessarily be related, but as events occur, the adult acknowledges a new event and draws from his library of associated personal past events to determine a logical solution to a problem. These influences are usually additive. That is, each experience builds upon a prior experience and these coupled together, provide for future justification in formulating decisions. "Cumulative experiences leads to the emergence of progressively more complex, higher-order accomplishments." (Ref. 6:p. 47) Although relative in nature, higher-order complex accomplishments are many times associated with executive decision-makers. In particular, an ASWC is a very good example to model the executive plaqued with

crucial problems to be solved. For example, in a hostile environment, the ability to recall past experiences from an ASWC's naval career, enables him to make the best decisions based on those experiences.

B. SHORT AND LONG TERM MEMORY

Information enters the brain through short term memory. "Information entering the short-term store is assumed to decay and disappear completely." (Ref. 7:p. 10) Existing information in the short term memory is therefore transient and must be constantly rehearsed in order to prevent its rapid decay. If the information is continuously rehearsed, it will enter into long term memory. However, if the desired information needed is recalled from long term memory, then the rehearsal acts as an aid to reinforce the already known information. This reinforcement serves as a tool to condition the human cognitive system and provides an asserting effect on future recall of this information. The positive effect associated with rehearsal of long term memory does enhance the speed and accuracy at which information can be recalled.

The rehearsal effect is in essence a learning process. What is learned or memorized, is stored in long term memory. This is to say, that as an experience builds upon another event(s), this event is being transfered from the library of the long term memory. It serves as the registration and storage of past experiences and events, much of which is the foundation of human knowledge. Additionally, long term memory which is dissimilar to short term memory, has infinite storage. It acquires information that has been sent from short term memory, catalogues and stores for future recall.

C. CHOICE TASK

"It is claimed that decision-making is more art than science and that intuition and experience are the main resources of a decision-maker." (Ref. 8:pp. 3-4) This analogy of decision-making reinforces the issue that emotions and human personalities tend to drive the chosen alternative for a particular action. In general, a choice task decision-maker has several options to follow which are different in many aspects. Each of the alternatives can require different actions and yield totally different outcomes. But of these alternatives, only a single solution must be selected. The thought of being able to choose two or more possibilities in theory is feasible, but is not an option for the choice task decision-maker. For this, a list must be made up of all the possible available options. This list is very important and a key component for the decision-makers. It is essential that the list be as thorough and complete as possible,

because its contents will hold all the choices for one to choose. Once complete, it is then considered a valid assumption that all possibilities have been examined and the list is complete and exhausted. Additionally, as the list increases in size, so does the number of stimuli, number of possible outcomes and thus, the difficulty for the decision-maker also increases and grows in complexity.

D. UNCERTAINTY

Uncertainty is also a key issue in the pursuit of attaining the best possible decision. "The realization that decision-making involves a comparison of alternatives, making it necessary to consider them, is, in itself, an advance. The realization that it is necessary to consider the uncertainties that may affect the situation makes people contemplate the outcomes of their decision-making much more carefully." (Ref. 5:p. 10) Without doubt, it is a natural human reaction for a decision-maker to make a choice from a list of alternatives and still possess some sort of uncertainty for the choice selected. However, to assist the decision-maker, the exhaustive list that has been created also serves as a tool to remove as much uncertainty as possible. Alleviating such uncertainty can be accomplished by acquiring more information. This leads the decision-maker back to the concept of information flow. It is imperative that information be passed as accurately as possible. By ensuring the utmost accuracy, uncertainty will be reduced. This is a major concern for the ASWC decision-maker. Specifically, ASW as mentioned, is not an exact science. Critical decisions for battle group survivability in an ASW threat environment, are dependent upon precise information with as little uncertainty as possible.

The real difficulty in decision-making belongs in the uncertainty of the event(s) being evaluated. Each uncertainty must be reviewed in depth prior to making a choice or conclusion. For some alternatives hold various levels of uncertainty. At times, uncertainty is combined and presented as an average such as surface ship sonar bearing errors. It is common to classify such error as an averaged number. However, in reality, bearing errors change under various acoustical conditions depending on the oceans environment. Therefore, the choice task decision-maker must realize the type of uncertainty when deciding on the optimum choice to the problem.

The above represents an overview of some of the more critical parameters that contribute to the decision-making process. At times it may appear as if the decision-making process was irrational. However, at the time the decision was

assessed, the decision-maker may have been tired, over stressed, emotionally involved in other problems, or a combination of any or all of these aspects. These are some reasons why decision-making can be influenced by the human personality. On the other hand, the influence of experience can be the key element to making a decision. This is readily seen in most people holding executive corporation positions, where experience breeds success, power and money. For the ASWC, his ability to draw on his own experiences, is what protects the battle group from the hostile submarine threat.

Therefore, to model or simulate the intricacies associated with a decision-maker, is very difficult, if possible. Validity is one of the most important constraints when modeling a decision-maker in a real world environment. ALPHATECH, INC., has developed such a way to approach a realistic ASWC decision-making model. This model will be overviewed next, by presenting the important concepts used for its development and subsequently its validation for real world applications.

IV. ASWC SIMULATION MODEL

There has been a tremendous amount of effort dedicated toward developing an ASWC simulation model. This model is to provide an ASW scenario for which an ASWC can utilize to evaluate battle group survivability in a hostile ASW environment. As we have seen, this is not an easy task to accomplish because of the countless variables that can enter into a given ASW encounter. ALPHATECH, INC., has developed such a simulation model. It enables an ASWC to make decisions regarding enemy submarine locations from a battle group, given specific acoustical information. As such, the model provides acoustical data from underwater sensors and allows the ASWC to decide on validity of the information and track the threat submarine with respect to the battle groups position.

The rationale behind this concept is in fact a very good way to approach an ASW scenario. Allow a decision-maker (ASWC) to absorb raw acoustical data, formulate an opinion as to the submarines position and track its movement as additional information is acquired. Additionally, the model must allow for the decision-maker to change a course of action as new and more concrete information is received. This is a good representation of a decision-maker and is one of the many objectives confronted by an ASWC. Therefore, the model possesses validity only as long as the received information supports current operational data and parameters associated with available acoustical equipment present on board US naval warships.

A. ALPHATECH, INC., ASSESSMENT SCENARIO

The ASWC simulation model developed by ALPHATECH, INC., is designed to model an ASWC's reaction in an ASW scenario. In order to justify the models performance, US Navy personnel (referred to as subjects) were utilized. All subjects had at some point in their career, a professional background in ASW. Additionally, all subjects possessed a working knowledge of tracking submarines when given bearing-only information. The results of the experiment using the Navy subjects would later be matched against the models performance. "If it can be demonstrated that the model has predictive validity, then construct validity can be demonstrated by showing that the performance distributions for the model and the subjects arose from the same underlying distribution." (Ref. 3:p. 23) Therefore, assuming that the subjects are truely

experts in bearing-only convergence zone tracking and the model performance corresponds to the subjects results, then validation has been demonstrated.

In order to assess the performance of the model, a data base of information needed to be obtained. This was accomplished by giving each subject two ASW scenarios. Both scenarios had common features, in that, the composition of the naval vessels in the battle group were the same. For each scenario, the battle group was heading due North at an advance speed of 15 knots. At different time intervals, the subjects would receive a piece of acoustical information from a particular platform. It is with this information, that the subject was required to determine what convergence zone or how far away the submarine was from the platform. This was accomplished by taking the raw data and plotting this information on a grid coordinate chart. The subjects were also required to plot this acoustical data taking into account both, the sensors bearing error and the vessels new location in the scenario. Table 1 below, gives the battle group composition that each subject used (Ref. 3:p. 28). It also denotes which platform had what sensor and the bearing errors associated with that sensor.

TABLE I
BATTLE GROUP COMPOSITION

BATTLE GROUP COMPOSITION		
Platform	Sensor	Bearing Error
Submarine (SSN/DS)	Towed-Array	+/-5
Frigates (FF)	Towed-Array	+/-5
Destroyers (DD)	Sonar	+/-10
Cruisers	Sonar	+/-10
Aircraft Carrier	-------	-----

Therefore, as each piece of information was acquired and plotted, the subjects could trace the submarines track with respect to the battle group. Also, the decision-maker (subject) could alter his thought pattern as the battle group advanced in the scenario. If the decision-maker made a poor decision as to the position of the

submarine, the subject could move the submarine to a new location without penalty. For example, if the subject believed that the enemy submarine was in the third convergence zone, but new information revealed a higher probability to be in the second, then the subject could orient his thought pattern to the second convergence zone. This is a very realistic and common approach quite often seen in the operational fleet today. Until an ASWC can obtain an area of high probability, most of the decisions are based on experience and his best guess as to the enemy submarines position.

B. ALPHATECH, INC., KALMAN FILTER APPROACH

ALPHATECH, INC., approached the ASWC model by mathematically modeling an ASW scenario. "With an appropriate model of a real-world situation, we should be able to predict certain outcomes or determine how the real world would behave if we implemented a particular alternative decision. In some instances, a model enables us to select the best or optimal decision." (Ref. 8:p. 16) One such method of mathematically modeling a real-world scenario and is used by ALPHATECH, INC., is the discrete Kalman filter. In general, the Kalman filter procedure gives satisfactory results, but there is evidence of erratic filter behavior. Therefore, when using the Kalman filter, caution should be exercised when formulating the matrix. In particular, there has been on occasion, premature collapse of the error covariance matrix, even under favorable operating conditions. This aspect is not advantageous to the model performance because it will ultimately cause the solution to diverge. Therefore, if or when solution divergence occurs, target-motion-analysis (TMA) estimations by use of the Kalman filter, can not always be guaranteed to be reliable.

The following discussion gives a description of the Kalman filter modeling process combined with mathematical excerpts taken from the written drafts provided by ALPHATECH, INC. Specifically, this discussion is on how they established the criteria for utilizing the discrete Kalman filter. The results from using this established criteria, has a very important and practical application. For, if the criteria is invalid, then the model will represent and provide little useful information.

The state vector x(t), represents the state estimater or motion of a submarine being tracked at time "t". It is assumed to be multivariate normal, with mean zero (Nx1). The states of the track hypothesis over a period of time, Δt, is modeled by the state equation:

$$x(t+\Delta t) = \Phi(t)x(t) + u(t),$$

where $\Phi(t)$ is the (NxN) state transition matrix and u(t) is the white Gaussian noise sequence matrix of zero mean with covariance Q(t). u(t) basically describes the randomness of the system as it moves from state x(t) to x(t+1).

The measurement or observation equation, y(t), which is the sonar contact data, is given by:

$$y(t) = Hx(t) + v(t).$$

The y(t) is the (Mx1) matrix of only sonar bearing data measurements. Additionally, y(t) is the vector of measurements made at time Δt. The measurements are assumed to be linearly related to the system state x(t) by the observation matrix H(t). H(t) is the (MxN) measurement geometry matrix and v(t) is a (Mx1) white Gaussian noise vector of zero mean with covariance R(t).

The between measurements on the basis of observations, provides an estimate of the states of the submarines track hypothesis and is noted as x(t|t). This is the best estimate given all measurements up to and including y(t) and has its covariance given by P(t|t). The mean and covariance of the state estimates over the period of time, Δt, is given as:

$$\hat{x}(t+\Delta t|t) = \Phi(t)\hat{x}(t|t),$$

and

$$P(t+\Delta t|t) = \Phi(t)P(t|t)\Phi(t)^T + Q(t),$$

where the uppercase T, represents mathematically, the transpose operation.

When a measurement $y(t+\Delta t)$ is obtained, the state and error covariance matrix of the track hypothesis are updated and given as:

State Update

$$\hat{x}(t+\Delta t|t+\Delta t) = \hat{x}(t+\Delta t|t) + K(t+\Delta t)\,(y(t+\Delta t) - H\hat{x}(t+\Delta t|t))$$

Kalman Gain

$$K(t+\Delta t) = P(t+\Delta t|t)\,H\,(H\,P(t+\Delta t|t)H^T + R(t+\Delta t))^{-1}$$

Error Covariance Update

$$P(t+\Delta t|t+\Delta t) = (I - K(t+\Delta t)\,H)\,P(t+\Delta t|t).$$

The state update equation has several features worth noting. First, the $(-Hx(t+\Delta t|t))$, is the predicted outcome of the measurement and secondly, the $(y(t+\Delta t))$, is the actual measurement. The two terms when combined together, yield the measurement residual.

The system model contains the state vector which is the Cartesian position and velocity of the track hypothesis. This track hypothesis is mathematically denoted in matrix notation as:

$$x(t) = \begin{bmatrix} \text{Bearing} \\ \text{Range} \\ \text{Course} \\ \text{Speed} \end{bmatrix} = \begin{bmatrix} px(t) \\ py(t) \\ vx(t) \\ vy(t) \end{bmatrix}$$

Additionally, the state transition matrix is given as:

$$\Phi(t) = \begin{bmatrix} 1 & 0 & \Delta t & 0 \\ 0 & 1 & 0 & \Delta t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

and the "Q" matrix allows submarine course and/or speed changes with "r^2" being the maneuvering variance given as:

$$Q = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & r^2 & 0 \\ 0 & 0 & 0 & r^2 \end{bmatrix}$$

This is not the complete approach which ALPHATECH, INC., chose to follow. For, the simulation model with all its various idiosyncrasies, would indeed have to be inspected. However, the Kalman filter approach to simulate an ASWC's decision-making process, is a very sound way to model such a task. The Kalman filter procedure is in fact, commonly accepted as one of the prime means to attain target-motion-analysis estimations and is one of the building blocks of this simulation model. Further, to no surprise, "simulation modeling is one of the most widely used techniques in operations research." (Ref. 9:p. 2)

Two issues need to be addressed regarding the experiment conducted by ALPHATECH, INC. First, in the experiment, the ASWC (subject) received acoustical bearing data information from the attack submarine operating in direct support (SSN/DS). This is very possible by means of Probe Alert (underwater telephone) or by means of a Slot sonobuoy (a submarine launched prerecorded information sonobuoy). However, this is very rarely used in fleet operational exercises and is highly unlikely to be used in a hostile ASW environment. Secondly, the bearing errors associated with the towed-array and sonars of +/-5 and +/-10 degrees are reasonably valid numbers. More importantly, there should be a weighting factor associated with the information received from these sensors. For a towed-array is more sensitive and an ASWC would most likely focus his course of action from information received from this sensor.

The US Navy today. is constantly being updated in surface ship overhauls and aircraft reworks in order to improve its capabilities in an ASW environment. For this reason, the following chapter presents a discussion as to what new sensors and equipment are available to an ASWC. This is a particularly important aspect when modeling an ASW encounter or an ASWC's reactions. It has already been stated, that a simulation model must represent the real world in order to be considered valid. Therefore, for this issue alone, the next chapter is provided to enhance the validity of the model presented by ALPHATECH, INC. If molded together, the model may in fact, yield a true updated representation of an ASWC's operational environment and a very useful model for training purposes.

V. OBTAINING ASW INFORMATION

In a hostile anti-submarine warfare environment, acoustical information and/or the enemy submarine location is extremely critical for the survival of a battle group. For this reason alone, it is imperative that the ASWC be knowledgeable of all the available assets by which he can obtain submarine information. Although, as we have discussed, obtaining actual raw acoustical data, can be a very arduous task. In that, open ocean water conditions can vary and the current generation of Soviet submarine radiated noise levels have been significantly reduced and thus, sensor detection is more difficult. The US Navy has recognized this new added dimension in the Soviet submarine fleet. Therefore, considerable amounts of money, time and effort, has been directed in upgrading the quality of existing shipboard acoustical decision aids to assist the ASWC.

A. AN/SQQ-89

The advent of the Soviet submarine capability to launch cruise missiles against surface platforms or carrier battle groups from long ranges, has placed new demands on US war vessels to acoustically detect these enemy submarines at multiple convergence zones. One such way of obtaining this acoustical data, is the new integrated Antisubmarine Warfare Control System (ASWCS) or commonly known as the AN/SQQ-89. This system is designed to detect, track, classify and localize multiple underwater submarines at extended ranges. Up to and including current shipboard Combat Information Centers (CIC's), ASW acoustical information has not been centralized. The ASWC attains acoustical information such as sonar contacts, via sound powered phones or loudspeakers. Raw data display is only attained by physically going to the console itself. The AN/SQQ-89 alleviates this problem. All system displays are centralized in CIC and allow the ASWC to simultaneously view all incoming and historical sensor data. Additionally, this multi-sensor system automatically provides the ASWC with an underwater torpedo fire control solution. The AN/SQQ-89 ASW Combat System is comprised of the following system elements:

* AN/SQS-53B/C...Hull Mounted Sonar

* AN/SQQ-28......Sonar Signal Processing System

* AN/SQR-19A.....Sonar Receiving Set

* SIMAS..........Sonar In-situ Mode Assessment System

* MK-116.........ASW Control System.

Each of these elements can operate autonomously, but in doing so, the automatic design features are lost. Thus, human interface is required to assist in data analysis and operator expertise becomes a key factor for the ASWC when making ASW decisions.

The AN/SQS-53B & C are basically an updated version of the existing AN/SQS-53A hull mounted sonar. Specifically, enhanced transducer abilities permit this sonar to extend its ping propagation to greater distances. It also provides for improved return ping resolution despite the depth of the submarine. Lastly, this sonar is capable of detecting, tracking and classifying submarines both actively or passively unlike current generation hull mounted sonars.

The AN/SQQ-28 system is the Light Airborne Multi-Purpose System (LAMPS MK III) helicopter shipboard data link receiver. It has and provides various functions which spacially ties the helicopter to the ship via a two-way pencil beam signal. Several of these key functions are:

1. Allows for two-way clear or secure radio communication.
2. Allows for two-way ESM contact information.
3. Allows for two-way air-to-surface radar coverage.
4. Simultaneously, process and displays raw acoustical data acquired from helicopter sonobuoys.

The introduction of this system now enables the surface fleet to remain covert by sending the helicopter well over the horizon. In doing so, the surface platforms or battle group can extend its ASW operating parameters several convergence zones farther away. Additionally, this tactic allows for extended ranges in ESM (Electronic Warfare Support Measures) and surface ship surveillance from the aircraft radar summary while remaining undetected.

The AN/SQR-19A is a Tactical Towed-Array (TACTAS) which is trailed underwater, several thousand feet behind the ship. The lengthy trailing distance is necessary in order to suppress its own surface ship generated noise. This new array

contains 48 acoustical hydrophone beams. It is capable of detecting radiated noise levels well into the low frequency spectrum domain and can passively detect, track and classify enemy submarines through all ocean sound propagation paths. Additionally, in view of the enhanced stability and sensitivity of this array, it changes the current operational fleet sprint-and-drift tactics required by its former predecessors. In that, the array can acquire and continuously maintain multiple contacts at excessive ship speeds while being in the towed configuration.

The acronym SIMAS, stands for Sonar In-situ Mode Assessment System. Basically, this system processes real-time ambient ocean water conditions transmitted from a bathythermograph and/or environmental water conditions measured from the AN/SQR-19A towed-array. Additionally, it has a comprehensive built in memory library of previous environmental predictions for the current desired operating area of the surface ship. The system will correlate the real-time raw data with historical data and will provide to the ASWC, its best guess as to depth settings for the towed-array, hull mounted sonar transducer depression angles and sonobuoy hydrophone depth settings.

The MK-116 is the ASW Control System and Underwater Fire Control System. However, there is one exception, the FFG-7 class ship, in that, they are configured with a WAP (Weapon Assignment Panel). In essence, the MK-116 is the "brain" of the AN/SQQ-89 system. It receives all information processed by the hull mounted sonar, towed-array, and the shipboard LAMPS helicopter sonobuoy processor. It correlates any or all of this acoustical data up to and including 99 different contacts. It also provides multiple contact management whereby, it will identify and categorize each contact as to its threat potential. Another capability of this system is its ability to do target-motion-analysis (TMA). With this capability, it will maintain all historical TMA information for three hours. This is a very beneficial aspect, for it plays a significant role for the ASWC decision-maker when operating in a multi-threat environment. One last key feature of the MK-116, is that it will evaluate the received acoustical data and automatically provide a torpedo fire control solution for LAMPS helicopter torpedo attacks and/or surface ship launched torpedoes.

The AN/SQQ-89 system in itself, is not a complete system that will be installed in all surface naval warships. There exists four different variations to this system depending on the ships class, taking into account the associated design mission task of that ship. Table 2 presented on the following page, is a representation of each

configuration package that will be installed onboard each ship class (Ref. 10:pp. G-4,G-6).

TABLE II
VARIANCES FOR THE AN/SQQ-89

Variances For The AN/SQQ-89			
DD(G)-963	FFG-7	CG-47	DDG-51
AN/SQS-53B	-----	AN/SQS-53B	AN/SQS-53C
AN/SQR-19A	AN/SQR-19A	AN/SQR-19A	AN/SQR-19A
AN/SQQ-28	AN/SQQ-28	AN/SQQ-28	AN/SQQ-28
SIMAS	SIMAS	SIMAS	SIMAS
MK-116	WAP	MK-116	MK-116

* DD(G)-963..represents Spruance(DD) and Kidd(DDG) class ships.
* FFG-7......represents the Oliver Hazard Perry class ships.
* CG-47......represents the Ticonderoga class ships.
* DDG-51.....represents the Arleigh Burke class ships.

The AN/SQQ-89 system is currently operational in both the Atlantic and Pacific Oceans. Its presence alone, has significantly strengthened the ASW capabilities of the surface battle group. For, real-time acoustical information, better computers yielding faster iteration time and higher quality as well as more sensitive equipment, all play an essential role in assisting the ASWC in his decision-making process. Furthermore, the addition of the automated feature, reduces operator error and allows the ASWC to evaluate his ASW course of action, based on his experience and a computerized solution as to the submarines location.

B. EXPERIMENTAL OVERVIEW

The experimental results from the ASW scenarios obtained by ALPHATECH, INC., serves as a fundamental foundation for which subsequent data analysis can be attained. The scenarios themselves, actually have little impact as to the significance of the model. This is because the scenarios merely act as a teaching aid to assist the decision-maker into formulating a course of action to follow. The ALPHATECH, INC., modeled scenario does fulfill the requirements of modeling an ASW scenario and does serve as a teaching aid despite its simplicity. It should also be noted, that increased amounts of model complexity for which an ASW scenario possesses, is probably a fair assessment of a potentially real hostile ASW environment. Additionally, if the magnitude of complexity is increased, it can also serve as a very good means by which to determine strengths and weaknesses of an ASWC decision-maker under various conditions. For, operational ASW requires continuous training, experiencing judgemental mistakes and/or acquiring a better perspective for future avenues to follow built upon previous lessons learned.

The experimental parameters utilized by ALPHATECH, INC., need to be reevaluated. Specifically, it does not truely represent a realistic representation of real world ASW in a hostile environment. We have already stated, that without a realistic representation, then the model loses its credibility and serves little to no purpose. The following discussion is directed toward this aspect and discusses what is available in the operational fleet today. This is not a complete discussion, because each battle group is comprised of different surface elements. For example, some battle groups have a battleship in lieu of an aircraft carrier and are commonly referred to as a Surface Action Group (SAG). However, for discussion purposes, the already established experimental battle group composition modeled by ALPHATECH, INC. (i.e., Frigates, Destroyers, etc.), will be utilized with emphasis on the AN/SQQ-89 ASW Control System.

Helicopters are a key element in any ASW encounter. Particularly, the LAMPS ASW helicopter. Although, it is a single unit in itself, when airborne, it serves as an extension to the surface ship by means of a two-way secure data link. It is capable of carring 25 sonobuoys, two torpedos and can remain airborne for over four hours without refueling. Additionally, if a refueling station is available, the LAMPS MK III helicopter can remain airborne for 30 consecutive hours before coming to rest inorder to perform required maintenance actions. These all weather aircraft are operational in

the fleets today and operate off of the experimental battle group composition such as frigates (FFG-7's) and destroyers (DD-963's). With the LAMPS aircraft capabilities, surface ships are able to investigate ASW contacts or areas-of-probabilities easily into a multi convergence zone environment.

The ALPHATECH, INC., ASW scenarios, begin with a detection of a subsurface contact in the second or third convergence zone by a surface ships towed-array. As the scenario developes, more information is attained by other ships hull mounted sonars or towed-arrays and thus, the decision-maker developes a hypothesis as to the location of the submarine. This is a very realistic assumption. However, the presence of the AN/SQQ-89 and the LAMPS aircraft, has certainly added a new dimension to an ASW scenario. Therefore, for the experimental scenario, if a submarine is believed to be within several convergence zones, then the model should allow the ASWC to launch a LAMPS helicopter for further investigation. This is a very common tactic used in the fleet today. The principle component in any ASW scenario or submarine encounter, is to detect the subsurface threat as early as possible and as far away from the battle group as possible.

The current generation of Soviet submarines are capable of operating in the low frequency spectrum where detection becomes extremely difficult. However, the new AN/SQR-19A Tactical Towed-Array, is a far more efficient and sensitive array. This new towed-array is capable of acquiring detection in the low frequency levels and at farther convergence zone distances. Additionally, after initial detection, the surface ship can make a course alteration thereby resolving any hydrophone ambiguity. This procedure is vital, for resolved ambiguity leads to a better refined area-of-probability. The enhancement of resolving bearing ambiguity significantly reduces the ASWC's reaction time and allows for less error in localization. This important concept should be incorporated into the ALPHATECH, INC., ASWC model because its increased capability in assisting the ASWC's decisions as to the submarines location. Therefore, in an ASW scenario, with a given AOP, the ASWC can launch his ASW LAMPS helicopter for further prosecution in excess of 100 nautical miles from the battle group.

Acoustical hydrophone sensing equipment in the past, have many times been positioned at less than optimum depths. However, SIMAS now provides the decision-maker with optimum hydrophone depth settings utilizing both current and historical acoustical environmental predictions. This new decision aid is very important because it allows ASW helicopter flight crews to preset hydrophone settings based

upon the environmental predictions. Once airborne, the helicopter does not have the capability to alter the sonobuoy depth settings. Thus, if the submarine is operating in the deep sound channel and sonobuoy settings are set for the upper surface layer or vice versa, then acoustical detection is highly unlikely. This also holds true for submarine radiated sound energy propagation for detection by the surface ship towed-array. Another major feature of SIMAS, is that it provides the ASWC with the best depth to trail the towed-array and optimum depression angles for the hull mounted sonar. Although difficult to model, the ASWC model should require the decision-maker to choose between shallow or deep hydrophone settings based upon predicted environmental conditions. This added creation requires the ASWC to draw on his knowledge of interpreting acoustical data predictions. Therefore, realism is once again entered into the model in order to simulate a real operational atmosphere.

In a multi-threat environment, contact management is very cumbersome and practically impossible without computer assistance. The MK-116 ASW Control System possesses a built in storage memory that maintains target-motion-analysis on multiple targets. This function is a tremendous decision aid for the ASWC, in that, the ASWC can visually track the location of submarines with respect to the battle group. Having this pictorial display, the ASWC can formulate his decisions for altering battle group course and speed of advance as well as positioning his ASW surface assets in order to obtain optimum ASW screening for the battle group. Additionally, the MK-116 will give the ASWC a computerized torpedo fire control solution based upon received acoustical data and target-motion-analysis of the submarine. This control system has major significance for an ASWC when operating in an ASW hostile environment. Therefore, for this reason, the real world simulation model should allow the decision-maker to utilize this target-motion-analysis information as well as allow battle group course changes away from the submarine threat.

Another key issue that has not been addressed at all, is the ASWC's availability of acquiring intelligence information of recent Soviet surface and subsurface movements. Usually, the ASWC will have the latest information as to the general location and hull class type of Soviet submarines believed to be operating in his vicinity. Vicinity here, can mean as much as 1000 square nautical miles. Although, this can encompass a large area of ocean, it does serve as a warning tool to assist the ASWC in possibly verifying a submarine contact. It also enhances the human operator's performance because he is alerted to a potential frequency band which can

be associated with the submarine threat suspected in the vicinity. The ALPHATECH, INC., model blindly places a battle group progressing along a given track and suddenly submarine contact information is acquired. Real world operations usually do not support this blind assumption. A submarine detection may come as a surprise, but its potential existance would normally be known. Therefore, the ALPHATECH, INC., decision-making model should provide the decision-maker with advanced knowledge and potential locations of any hostile submarines. This is not always a guarantee, but it does provide the necessary stimulus for an ASWC to be aware of his threat environment. Armed with this information, it will allow the ASWC to match his acoustical knowledge, threat knowledge and experience to validate a submarine signature. Thus, battle group orientation and decisions to dedicate which surface and/or air assets against specific submarine contacts, becomes a realistic scenario.

The topics discussed above reveal in a broad sence, where the US Navy's capabilities are today and provide some in-sights as to its future course of direction with regard to combating the ASW problem. ASW is fascinating in nature and quite unique, in that, no two scenarios are alike. ASW modeling, requires complete understanding of the variables which can significantly alter an encounter. The model must also be able to adjust to the human decision-making process. There are no concrete step by step solutions to any given ASW scenario because of the constantly changing environmental conditions. Therefore, it is essential that the model design parameters must be related to actual specifications or equipment available to real life situations.

The real world ASW problem has been receiving a tremendous amount of attention and will continue to do so, now and in the future. One such way of looking at the problem is to devise a simulation model. A model that reflects a realistic approach to a true operational environment. Thus, as circumstances change or techniques become improved, the simulation model must also be upgraded to reflect these alterations.

VI. THE ASWC DECISION-MAKER

Thus far, this study has introduced several issues that confront an ASWC. They range from knowing the enemy threat and its capabilities to some of the facets that effect a decision-maker. The latter, requires further amplification with respect to modeling an ASWC. The ASWC decision-maker model developed by ALPHATECH, INC., is a representation of one approach to modeling an ASWC decision-maker. In doing so, they justified their decision-maker's ability to react in an ASW environment, by means of an ASW tracking scenario. Specifically, a subject received bearing only information from a naval vessel at a particular time and position. At subsequent time intervals, an additional piece of bearing information would be received and thus, the subject would attempt to track the submarine contact utilizing this bearing only information.

This concept of modeling an ASWC, does constitute a valid representation of an ASWC decision-maker; however, there are other aspects to the decision-making scenario that need to be examined. Several of them have already been addressed, such as, the use of ASW helicopters. This added feature alone, could drastically influence an ASWC's decision-making process. This is not to say that the approach ALPHATECH took was wrong, but it does point out that it falls short of accurately representing a real world operational environment. It represents only a small portion of what actually evolves in an ASW encounter. It is the nature of these key issues and there resulting impact, that will significantly effect or alter an ASWC's perception and/or reaction. Therefore, an opposing viewpoint is provided to enhance the understanding of an ASWC. To do this, a conceptual model of an operational ASWC is furnished in an effort to support this viewpoint.

The chosen way to present a discussion of these arguments is by means of an example. This example, as demonstrated in the following figure, is a snapshot picture of a generic carrier battle group transiting through an open ocean. It is designed to enhance credibility, by pictorially mocking a typical battle group with its associated ASW assets.

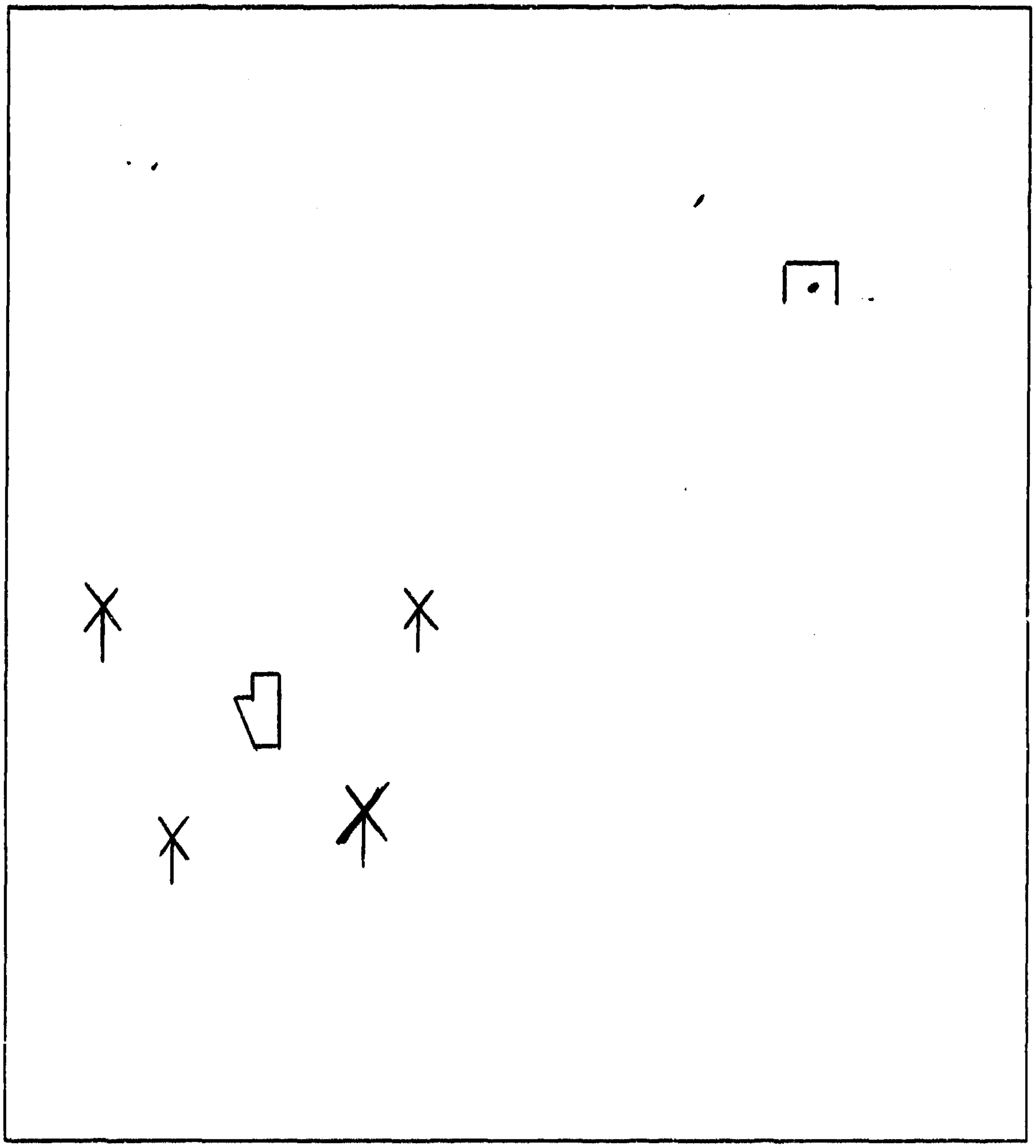

Figure 6.1 Carrier Battle Group.

 = Aircraft Carrier

 = ASW ship with towed-array and hull mounted sonar

 = ASW LAMPS helicopter

Before we subject the ASWC to a potential submarine contact, we need to momentarily digress and revisit an important topic; the presence of intelligence. In general, an ASWC will have knowledge of submarines operating in the proximity of his transiting path. In particular, he receives a continuous update of the various submarine class hulls by type and by last known operating areas. This information is critical because detected submarine frequency signatures can be compared to those identified in the intelligence reports. The importance here, is that if there is a correlation between the two, then an ASWC will undoubtedly regard this as a valid contact. Thus, his decision process in classifying the contact, is cluttered with less uncertainties. On the other hand, if the signature does not correspond to known intelligence, he may make the assumption that it is a false contact or a potentially valid contact that did not appear in the intelligence reports. In lieu of the latter, it may serve as the triggering spark in his decision-making process for further investigation. Whichever is the case, an ASW scenario is born.

Having addressed the decision applications associated with intelligence, we now must conceptually look at the ASWC in his decision-making method when acoustical contact information is acquired. In particular, we are interested in how he values or weights information from his sensors. In some cases, the decision can be very easy, such as, visual sighting of a submarine, which is not an uncommon occurence. Or it can be quite difficult, especially if two or more sensors report contact information on a specific contact, but for some reason, they are not reporting the contact in the same location.

To put a weighting factor on a particular sensor, can be a confusing and rather difficult task because a particular sensor may not be at its peak performance. To expand on this issue, if a trailed towed-array has its very low frequency (VLF) hydrophone beams inoperative, then that frequency domain of potential information will not be available to the sensor operator or the ASWC. Loss of this valuable frequency spectrum will certainly pose a major problem on the ASWC decision-maker in his performance of ASW. He may perceive this sensor casualty as a major degradation and thus, it will carry an insignificant weighting factor. The counterpoint to this issue, is that when the towed-array is fully functional, the ASWC may value this as his primary sensor when making his decisions. Therefore, a dilemma exists. That is, he may regard a VLF degradation, as say, 20% probability of detection (Pd). On the other hand, if the towed-array is fully functional, it may carry a weighting factor of 100% Pd.

To complicate matters even further, we can address the same example but with two sensors. If under normal circumstances, an ASWC entrusts 100% Pd in attaining acoustical information from a fully functional towed-array and only say, 50% Pd from a hull mounted sonar in the passive mode, then the weighting factors of 100% and 50% respectively is conceptually established. If he acquired contact information on his hull mounted sonar, then he places a 50% probability on that particular information with respect to it actually being a valid contact. However, returning to our example, if the towed-array becomes degraded in the VLF domain, then he will orient his weighting criteria from 100% to 20%. But, for the hull mounted sonar, he may conceptually elevate his weighting factor from 50% to say, 80% Pd. This increased weighting factor, presents an interesting aspect. With the major degradation in the towed-array, he may determine that his hull mounted sonar is the only fully reliable sensor available. Therefore, lacking reliable towed-array information, he will place higher emphasis on the sensor that is fully functional. Thus, with greater emphasis focused on the hull mounted sonar's ability, then correspondingly, there will be an increase in its weighting factor.

Now that we have demonstrated by this rather simple example, how an ASWC's decision-making process can easily be influenced by equipment malfunctions, we can readily note the amount of difficulty behind modeling an ASWC decision-maker. For ease of future discussions, the assumption will be made that there are no sensor degradations. Although, it is important that the reader keep in mind, that sensor equipment degradation and/or total failure, is a very common occurence.

Referring back to the pictorial example, there exists ships having towed-arrays, hull mounted sonars and an ASW LAMPS helicopter airborne. The airborne helicopter does not serve in the capacity of a search vehicle, because it is regarded as a reactionary asset. The ASWC can not disregard this airborne helicopter, for he is responsible for providing airspace flight safety. Additionally, the ASWC is not concerned with attaining acoustical information from the helicopter, because no sonobuoys have been expended. This leads to the sole reliance of acquiring submarine contact by means of his surface ship's towed-array and/or hull mounted sonar. Acknowledging this, the weighting factor must be brought back into play because the ASWC is confronted with which of the two sensors are the best element to procuring acoustical information.

The advent of the AN/SQQ-89 system into the fleet today, has brought significant changes that affect an ASWC's decision-making process. Not only is it an integrated system that also has the ability to operate autonomously, but the significant advantage gained, is that it incorporates the latest in state-of-the-art technology. In particular, the towed-array hydrophone sensitivity with associated computer support equipment, can easily detect submarine frequency signatures beyond multiple convergence zones. This enhanced asset alone, makes the AN/SQR-19A towed-array, the primary sensor that an ASWC utilizes. Although the hull mounted sonar has been improved in the AN/SQQ-89 system, it currently can not achieve (under other than ideal water sound propagation conditions) the detection distance as compared to the newly advanced towed-array. Therefore, an ASWC places a very high weighting factor on the towed-array for initial detection.

Once an initial detection has been made, the ASWC will attempt to ascertain if other units attained the same contact. If not, he may be faced with the decision to relocate other units with the idea of acquiring a two sensor fix and thus, a localized area of probability can be achieved. Another aspect along this line of thought, is that, the ASWC is not only attempting to gain a fix, but once achieved, he wants to ensure that he maintains contact. This brings about various considerations that he needs to decide upon. If he changes the integrity of the ASW battle group screening, he may leave a void in its protection. On the other hand, the change may enhance the situation by refining the location of the datum. How he arrives at this decision is a judgement call. However, it can not be taken lightly and must be carefully evaluated. He may be increasing his vulnerability and thereby, inviting potential disaster.

Following the discussion previously presented, the ASWC has an additional hurdle for which a decision needs to be made, in that, he still has an airborne ASW asset that is available for utilization. If he does elect to send the helicopter to the datum, he is confronted with several decisions that also need to be considered. These may encompass the amount of fuel onboard, launching a second helicopter or the time and distance to datum that the helicopter would need to travel. Therefore, as an ASWC decision-maker, he is confronted with several issues all at once, that require his attention. It is a multi-dimensional problem. Once initial contact is attained, his thought process is moving ships, helicopters or a combination of the two. Confronted with all of these thoughts, he also is simultaneously considering the tactical advantages/disadvantages, safety factors and potential repercussions once his decision is executed.

Along with these considerations, another topic is worth examining. Utilizing the pictorial example, the environmental surroundings need to be discussed. The ASWC must rely upon his experience and acoustical background knowledge, as he determines how to effectively deploy his sensors. If deployed improperly with known water conditions, detection may not occur. For this reason, it is imperative that he possess a keen understanding of how sound propagates in water. For optimum deployment results, he must decide upon whether towed-arrays should be trailed deep, shallow or a mix of the two. Additionally, this also affects the helicopter. Once airborne, sonobuoy depth settings can not be altered. These are important issues, for if detection from a deep trailed towed-array is acquired and the helicopter has only shallow setting sonobuoys, then he has lost a valuable asset for attaining acoustical information. Fortunately, the AN/SQQ-89 system has SIMAS incorporated. This decision aid is of invaluable assistance to an ASWC. Its data bank of historical acoustical predictions coupled with, real time acoustical data obtained from a bathythermograph, gives an ASWC a "best depth" setting for deployed sensors. Thus, combining results from SIMAS and his own environmental predictions, he must decide upon the optimum tactical deployment of his sensors.

There exists one last aspect that affects the ASWC decision-maker. This being, how he perceives the effectiveness of his personnel. This perception, is determined by various inputs, such as, effectiveness of training, personalities, fatigue, attitudes and professionalism. Without adequate training, the overall readiness of an ASW asset is degraded. If morale is low, personnel attitudes will be affected and performances will decrease. If operators are fatigued due to excessive job demands, then this also decreases their abilities to function in stressful situations. Additionally, the ASWC may favor a particular ship or flight crew because of there stronger professional abilities. Perceptions acquired from these sort of issues, drive an ASWC to formulate opinions that may carry a significant value or weighting factor. This will become evident, when he makes decisions that require involvement of ASW assets in a scenario.

We have discussed several topics that affect an ASWC's decision-making process. Specifically, intelligence, equipment casualties, the various ramifications associated with positioning and/or reorietation of ASW assets, environmental considerations with regard to acoustical predictions and some of the problems associated with his personnel. Taking each issue separately and allowing an ASWC to make a decision

based upon that issue, is a conceivable task to analyze. However, to tie all of these together and link them to an ASW scenario, is a very difficult task in itself, let alone attempting to model. But, this is the reality that an ASWC must regularly deal with. When making his decisions, he must mold all of these issues together in order to formulate the best possible course of action to follow. The following figure represents how this decision-making process can be conceived. In that, an ASWC receives various inputs that may occur at the same time and yet, the result is one decision.

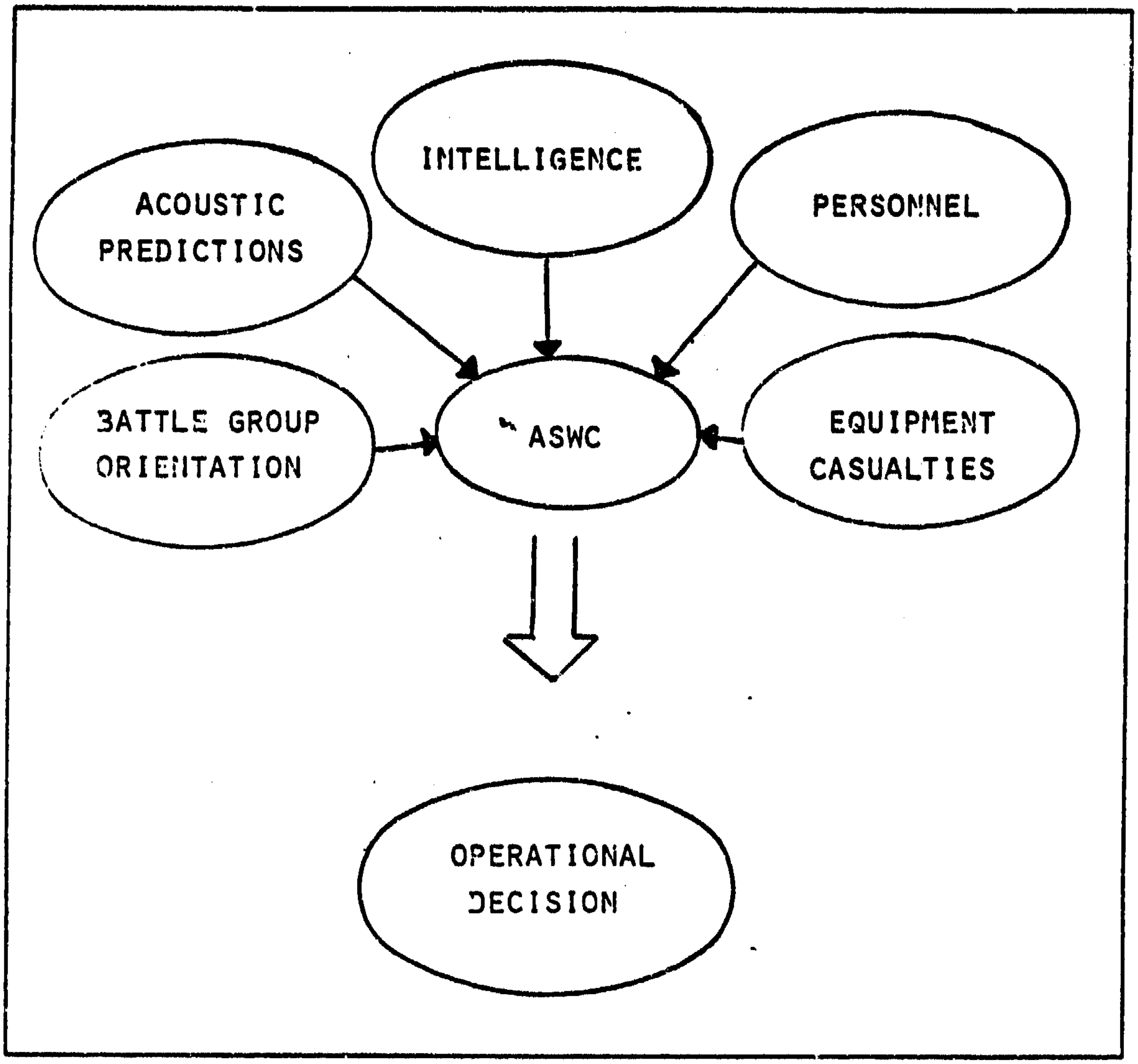

Figure 6.2 Decision-Making Process.

We have also discussed the topic of a weighting factor. Each issue presented, has several internal elements to which an ASWC places emphasis upon or increased/decreased significance. This may vary with the current state of the operational environment and/or the readiness capabilities of his ASW assets. In addition to this, he places a weighting factor on each one of these major issues. For example, if he is involved in tracking a submarine, he may place less emphasis on intelligence and a higher concern on reorienting his ASW assets. Thus, depending upon how much he weights each issue, directly reflects on how he makes his decisions.

This conceptual ASWC is a unique individual that is solely responsible for the ASW posture of the battle group. In an ASW encounter, we have seen by this discussion, that the ASWC is continuously overwhelmed with various problems that are different in nature, but, all of which tie together. Thus, utilizing his knowledge, experience and expertise, he makes the critical decisions that result in the survivability of the battle group.

VII. CONCLUSIONS AND RECOMMENDATIONS

This study has identified the Soviet submarine ASW threat capabilities that can be confronted in a hostile environment. Soviet launched cruise missiles, torpedoes and quiet submarines all demonstrate that a potential threat does exist and should not be taken lightly. To counter this, rigorous fleet battle group exercises must be continued in order to maintain the skills necessary for detecting, localizing and destroying the enemy submarine force. This particular aspect takes time, money and numerous manhours to accomplish. Further, surface ships need inport time to rework casualty components as well as crew shore leave for morale purposes. Therefore, other means to train key personnel in the field of ASW is essential.

ALPHATECH, INC., devised one such approach by simulating an ASW scenario and allowing an ASWC to track submarine targets, given certain pieces of information. Specifically, the ASWC received acoustical bearing information from surface ship hull mounted sonars and towed-arrays and submarine towed-arrays. Equipped with this information, the ASWC then performed submarine target-motion-analysis using a grid lock coordinate system. This is a good way to model an ASW scenario. It keeps the ASWC decision-maker constantly aware of his profession while preserving the reactionary skills of an ASW threat encounter. However, to ensure that the preservation of this proficiency is maintained, the ASWC model must support real world conditions that are available in an operational ASW arena.

The following recommendations are submitted in order to enhance real world conditions to the ALPHATECH, INC., ASWC decision-making model.

1. Provide the ASWC with some sort of intelligence. Give potential submarine threats operating in the vicinity of the battle group. Include frequency and harmonics associated with the threat submarine hull class. This acoustical information should be related to components that usually generate and dissipate detectable radiant noise (i.e., turbine generators, propulsion blade rates, etc.). Although a new field under investigation, artificial intelligence may be an alternative feasible input to give to the ASWC.
2. Provide acoustical environmental predictions to the ASWC prior to commencing the scenario. This will satisfy the use of SIMAS and will allow the ASWC to formulate his thoughts as to optimum depth settings for towed-arrays and air launched sonobuoys.
3. Remove from the existing scenario the use of a Direct Support Attack Submarine (SSN/DS). In almost all cases, they operate independently from the battle group. Having them provide information is not a realistic parameter primarily due to the loss of maintaining a covert posture.

4. US submarines operate well in advance of a battle group. Before the simulated scenario begins, the ASWC should be aware of the sectors for which each submarine is operating within. This is normally called the "no-tack" submarine area. This designated no-tack area, establishes the boundaries within which no weapons can be launched due to the possibility of the contact being a friendly submarine.

5. Incorporate the LAMPS MK III ASW helicopter into the model. They currently operate off of FFG and DD class ships and are used extensively as the prime tool to extend the battle groups ASW capabilities easily into multiple convergence zones. Additionally, extended ASW coverage is significantly increased if more helicopters are used.

6. When utilizing the LAMPS MK III ASW helicopter, the ASWC will be concerned with placement of sonobuoys. A good mathematical model to do such is the least squares passive tracking algorithm. This time based algorithm can provide for how a sensor can be placed ahead of where the contact is expected to be at some time in the future. It also will give how an aircraft should be vectored in degrees true and for how far in nautical miles.

7. Give the ASWC the flexibility to alter the course of the battle group. This is especially critical in an operational environment when a submarine is detected. If a submarine is going to attack using torpedoes, it must fire with the surface vessels within the limiting-lines-of-approach. Therefore, an ASWC will usually alter the main body of the battle group away from the firing envelope of the submarine.

8. Another motive for altering a surface ship is to resolve any bearing ambiguity and to refine the area-of-probability of the submarine contact. Once a detection occurs, the ASWC should be able to orient another surface vessel using its own sensors, to determine the contacts position. If a cross fix results, then aircraft should certainly be launched to attain pin-point localization.

9. All ASWC's are qualified Surface Warfare Officers (SWO) with a US Navy designator of 1110. Therefore, when seeking out a data base to validate the decision-making simulation model, the results should come from subjects with this background. Additionally, these subjects should be graduates of the Surface Warfare Officers Department Head School with an Operations Department specialty, located in Newport, Rhode Island. These individuals have had extensive training in ASW and are usually designated Tactical Action Officers (TAO's) and are graduates of the TAO school. Thus, for data collection based on knowledge and experience, these expert Navy specialists can provide the necessary foundation to justify the validity of the simulation model.

10. The MK-116 ASW Control System should be incorporated into the model to assist the decision-maker. It can provide target-motion-analysis on multiple contacts, but more importantly for this model, it absorbs all real time data from all sensors and gives the ASWC a computerized solution to where the contact is located with respect to the battle group.

11. The scenarios given to the subjects for data base collection were very basic. The Navy subjects are knowledgeable, experienced and operate efficiently in a high tense ASW environment. Therefore, increase the complexity of the scenarios. Make the subjects think. Use their unique expert talents to attain the desired experimental results. Thereby, the collected data base becomes a very sound foundation to reflect upon for model verification.

This study has discussed many of the problems associated with an ASW confrontation. The flow of acoustic information can be distorted because of the problems associated with the man-machine interface. However, the advent of the AN/SQQ-89 significantly reduces this operator error. Also, the human decision-making process has several unique behavioral characteristics which rely on

knowledge and experience. These elements are affected by uncertainty and the ability to recall upon past experiences to make a logical choice between several alternatives. These alternatives may be simple in nature or very critical, such as the survivability of a battle group, which lies solely on the course of action chosen by the ASWC. Therefore, a simulation model must possess flexibility and acknowledge that human decision-making can at times be confusing for the decision-maker may be choosing a course of action on mere instinct.

The Kalman filter approach that ALPHATECH, INC., utilized to mathematically model an ASW scenario was a very good choice. It does not give a perfect solution, but it does produce satisfactory results and is probably the best technique available to predict outcomes given several alternatives.

The ALPHATECH, INC., simulation model is a good decision-making model. It allows for an ASWC to track a submarine by means of a scenario with given pieces of information. Although, some of the existing parameters are unlikely to occur in a real world operational environment such as, submarine towed-array information. But it does serve as a training aid to enhance an ASWC's efficiency. This is especially true if the model reflects real world conditions. Therefore, given the recommendations presented earlier, if incorporated, then perhaps a viable justification for the models validity exists. Additionally, if the model represents a real world environment, then this should satisfy the requirements to model an ASWC's decision-making process. Thus, the objects and goals established by ALPHATECH, INC., to mathematically model an ASWC's decision-making process, has been attained and should be utilized as a fleet input to train Naval Antisubmarine Warfare Commanders.

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